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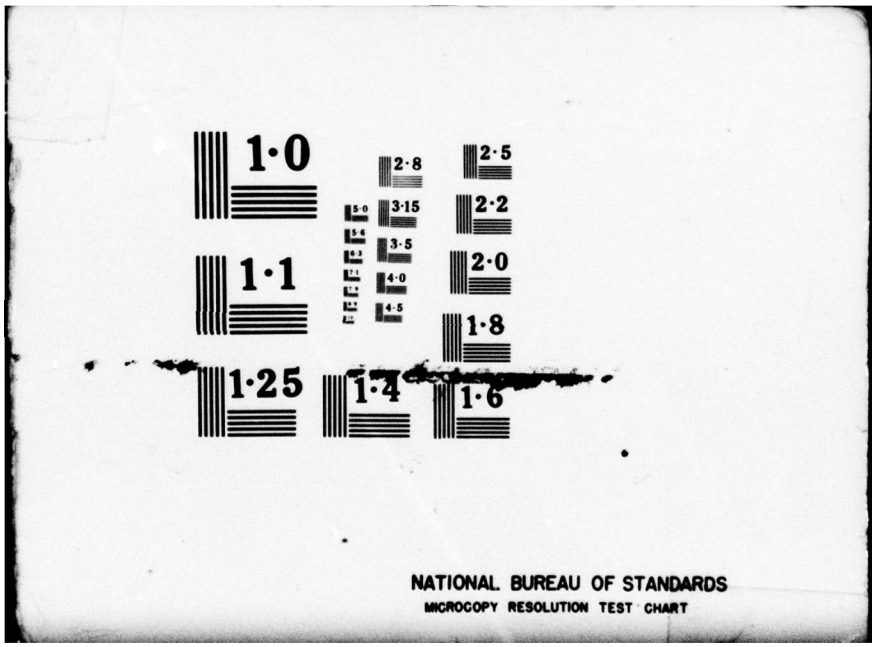
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DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-52

DESIGN OF A LABORATORY MICROCOSM FOR EVALUATING EFFECTS OF DREDGED MATERIAL DISPOSAL ON MARSH-ESTURINE ECOSYSTEMS

by

Ecosystem Research and Simulation Division
Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

August 1978
Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

under DMRP Work Unit No. ID08

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30 September 1978

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1. The work reported herein was undertaken as Work Unit 1D08 of Task 1D, Effects of Dredging and Disposal on Aquatic Organisms, of the Corps of Engineers' Dredged Material Research Program. Task 1D was a part of the Environmental Impacts and Criteria Development Project (EICDP), which had a general objective of determining on a regional basis the direct and indirect effects on aquatic organisms due to dredging and disposal operations. The study reported herein was part of a series of research contracts developed to achieve the EICDP general objective.

2. This research evaluated the use of laboratory microcosms for evaluating environmental effects of dredged material disposal in salt marsh-estuarine systems. A preliminary design was formulated consisting of three separate compartments - high marsh, tidal creek and creek bank marsh, and estuary. These compartments were interconnected with pumps controlled by a series of timers for simulating tidal cycles. The approach was tested in an experiment designed to compare the nutrient flux and biological community metabolism of a natural salt marsh with a marsh developing on dredged material. For purposes of evaluation, two microcosms were constructed, each containing a salt marsh tank and a tidally linked estuary tank. One of the salt marsh microcosms contained natural marsh substrate while the other contained dredged material planted with *Spartina alterniflora*. Differences in nutrient cycling and metabolism between treatment and control marsh microcosms were detected and related to the greater metabolic activity associated with the larger pool of organic detritus in the natural marsh. Differences in the marsh microcosms resulted in differences in basic ecosystems functions of the tidally linked estuary microcosms. Differences in the natural marsh and the marsh established on dredged material would be expected to decrease as organic detritus built up on the surface of the dredged material marsh through natural processes.

3. Rates of nutrient flux and community metabolism in the microcosms compared favorably with published values from field studies.

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4. This report discusses final design recommendations and the use of microcosms for addressing environmental effects of dredged material disposal. Marsh-estuarine microcosms appear to be useful for determining effects of engineering activities and resource management alternatives on many basic ecological functions of salt marsh-estuarine systems. When similitude is achieved between microcosms and field prototype for rates of basic biological and chemical processes, microcosm results expressed on a unit area basis can be extrapolated to field situations for purposes of impact prediction.

5. The information in this report summarizes the present knowledge relative to the use of marsh-estuarine microcosms for predictive evaluation of environmental effects of dredged material disposal on marshes. It is expected that this information will be of significant value to those concerned with technical evaluation of disposal alternatives.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

(14) WES-TR-D-78-52

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report D-78-52
2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER

(6) 4. TITLE (and Subtitle): DESIGN OF A LABORATORY MICROCOSM FOR EVALUATING EFFECTS OF DREDGED MATERIAL DISPOSAL ON MARSH-ESTUARINE ECOSYSTEMS.

(9) 5. TYPE OF REPORT & PERIOD COVERED: Final report, Jul 73-Oct 74

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): Ecosystem Research and Simulation Division

8. CONTRACT OR GRANT NUMBER(s)

(12) 54p.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Environmental Laboratory
P. O. Box 631, Vicksburg, Mississippi 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
DMRP Work Unit
No. 1D08

11. CONTROLLING OFFICE NAME AND ADDRESS
Office, Chief of Engineers, U. S. Army
Washington, D.C. 20314

(11) 12. REPORT DATE: August 1978

13. NUMBER OF PAGES: 48

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

(10) R. M. Smart
R. L. Eley
J. M. Falco

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Dredged material	Estuaries
Dredged material disposal	Microcosms
Ecosystems	Salt marshes
Environmental effects	Tidal marshes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The use of laboratory microcosms for evaluating environmental effects of dredged material disposal in salt marsh-estuarine systems was evaluated. A preliminary design was formulated consisting of three separate compartments - high marsh, tidal creek and creek bank marsh, and estuary. These compartments were interconnected with pumps controlled by a series of timers for simulating tidal cycles. Areas of the various compartments as well as tidal height and exchange were based on data obtained for Barataria Bay, a salt marsh estuary

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in southern Louisiana. Data on nutrient dynamics as well as productivity and respiration were obtained and compared with data for the prototype.

Based on results of the initial experiment, improvements in microcosm design were made, and the approach was tested in an experiment designed to compare the nutrient flux and biological community metabolism of a natural salt marsh with a marsh developing on dredged material. For purposes of evaluation, two microcosms were constructed, each containing a salt marsh tank and a tidally linked estuary tank. One of the salt marsh microcosms contained natural marsh substrate while the other contained dredged material planted with Spartina alterniflora. Differences in nutrient cycling and metabolism between treatment and control marsh microcosms were detected and related to the greater metabolic activity associated with the larger pool of organic detritus in the natural marsh. Differences in the marsh microcosms resulted in differences in basic ecosystem functions of the tidally linked estuary microcosms. Differences in the natural marsh and the marsh established on dredged material would be expected to decrease as organic detritus accumulated on the surface of the dredged material marsh through natural processes. Rates of nutrient flux and community metabolism in the microcosms compared favorably with published values from field studies.

Based on these studies, final design recommendations were formulated and the use of microcosms for addressing environmental effects of dredged material disposal was discussed. Marsh-estuarine microcosms appear to be useful for determining effects of engineering activities and resource management alternatives on many basic ecological functions of salt marsh-estuarine systems. When similitude is achieved between microcosm and field prototype for rates of basic biological and chemical processes, microcosm results expressed on a unit area basis can be extrapolated to field situations for purposes of impact prediction.

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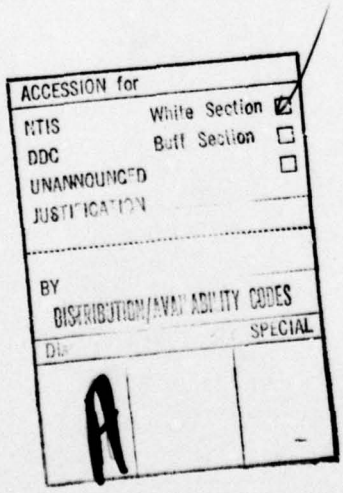

PREFACE

This investigation was conducted as part of the U. S. Army Corps of Engineers Dredged Material Research Program (DMRP). The DMRP is sponsored by the Office, Chief of Engineers (DAEN-CWO-M).

The study was conducted during the period July 1973 to October 1974 at the U. S. Army Engineer Waterways Experiment Station (WES) by the Environmental Laboratory (EL) under the direct supervision of Dr. J. M. Falco, Team Leader, Ecosystem Research and Simulation Division (ERSD), and the general supervision of Dr. R. L. Eley, Chief, ERSD, and Dr. John Harrison, Chief, EL. Messrs. F. J. Cali, III, J. H. Carroll, W. B. Ford, R. M. Smart, and T. C. Sturgis; Mses. L. C. Egger, P. C. Kerr, M. C. Landin, and K. L. Wong; and Dr. D. Gunnison, all of ERSD, conducted the experiments. Mr. Smart and Drs. Eley and Falco analyzed the data and prepared the technical report. The EL Analytical Laboratory performed all chemical analyses under the supervision of Mr. J. D. Westhoff, Chief. Drs. J. W. Keeley, C. J. Kirby, and R. M. Engler were project managers for the DMRP.

Directors of the WES during the preparation and publication of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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DESIGN OF A LABORATORY MICROCOSM FOR EVALUATING EFFECTS OF DREDGED MATERIAL DISPOSAL ON MARSH-ESTUARINE ECOSYSTEMS

PART I: INTRODUCTION

1. This report presents results of experimentation to determine the feasibility of using laboratory microcosms for evaluating effects of dredged material disposal on the ecology of salt marsh-estuarine systems. The term "microcosm" was coined by ecologists to refer to laboratory simulations of natural ecosystems. Salt marshes and adjacent estuaries form highly interactive systems because of tidal fluxes (Figure 1). Because of these interactions at the biological community and systems level of organization, environmental perturbations may modify important ecosystem functions in ways that are undetectable by evaluating direct effects on selected biological and chemical components (Eley, Falco, and Kirby 1975). It is important to consider potential effects on basic ecosystem functions such as mineral cycling, as well as to consider more direct effects on water quality, wildlife, and fisheries, because changes in these basic functions ultimately will result in changes to more obvious indicators of environmental quality.

2. The microcosm approach was selected for investigation because it offers potential to evaluate impacts at the systems level, rather than impacts on individual species; to control and manipulate environmental conditions; to conduct repeatable treatment versus control experiments; and to use special experimental techniques such as radiotracers.

3. Field conditions in many cases are not amenable for conducting controlled, repeatable experiments. In evaluating alternatives, such as options for dredged material disposal, it frequently is necessary to make comparisons of impacts on a relative basis. Therefore, a capability to investigate potential environmental effects in a controlled, repeatable manner is very desirable. Problems encountered in field studies include spatial and temporal variability in environmental

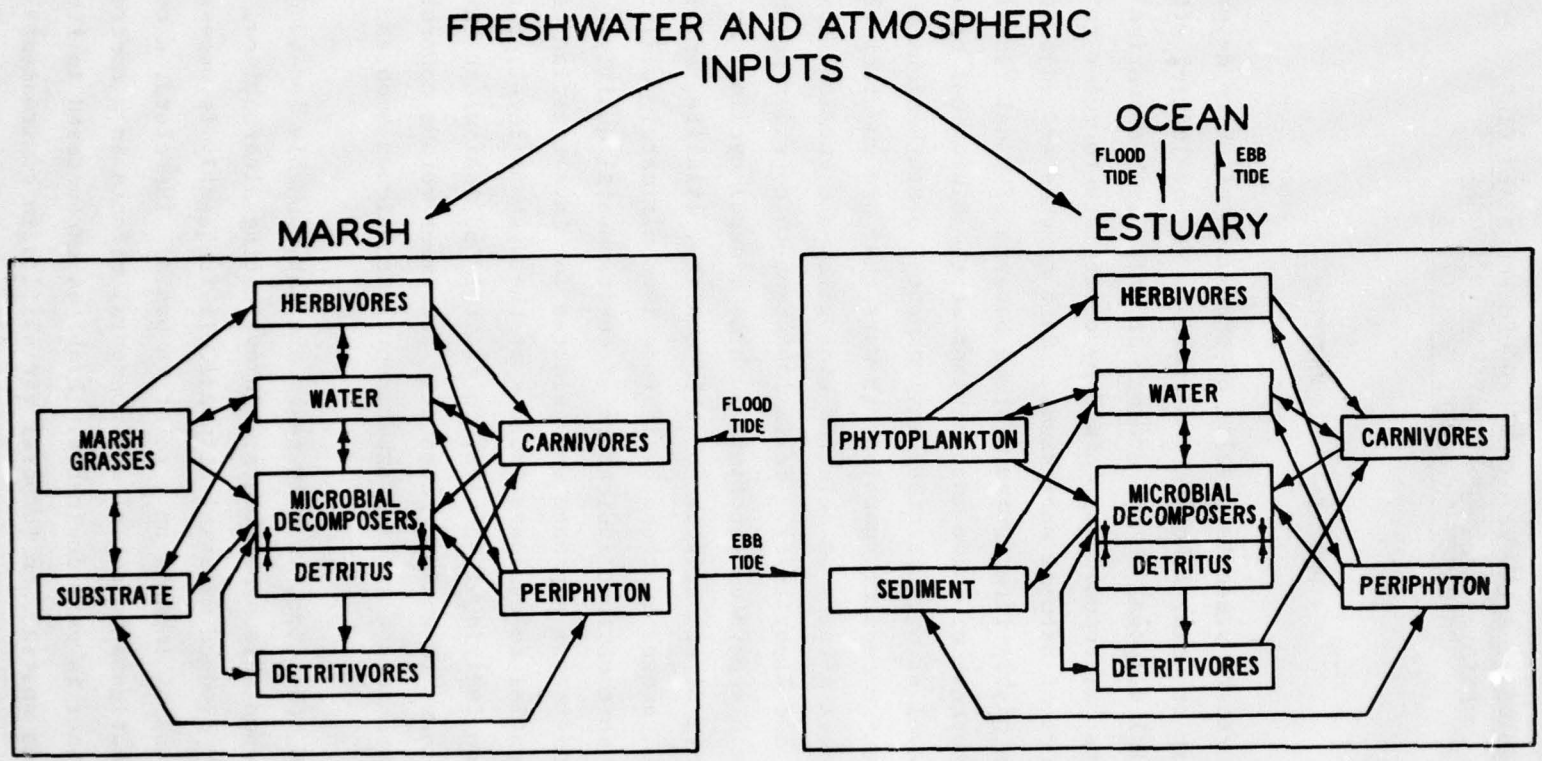


Figure 1. General compartment model of a marsh-estuarine ecosystem

conditions and constituent distribution and difficulty in controlling and monitoring forcing variables. Although use of microcosms circumvents these limitations, there are inherent limitations on the size of microcosms and on the amount, accuracy, and precision of replication. These limitations are set to a great extent by the amount of available controlled-environment space. Increases in microcosm size and space requirements generally result in decreased environmental control as well as the possibility of increasing experimental variability. The size of microcosms and space availability become especially important when sampling requires the sacrifice of a portion or all of an experimental unit because of destructive testing.

4. Microcosm experiments usually are of a relatively short duration (weeks or months rather than years) due to problems associated with containing biological populations within artificially imposed boundaries. Some organisms, notably insects, in the absence of natural predatory controls, can reach abnormally high densities and result in undesirable study conditions. The depletion of essential nutrients and the buildup of metabolic products also restrict the duration of aquatic microcosm experiments if static rather than flow-through conditions are maintained.

5. Many questions about environmental problems associated with dredged material disposal potentially could be addressed in a cost-effective manner through microcosm testing. However, before microcosm testing could be considered practical for widespread application, guidance on the design and maintenance of realistic laboratory simulations of marsh-estuarine ecosystems was required. The purposes of this investigation were to evaluate the potential of laboratory microcosms to simulate basic ecological functions of a marsh-estuarine system as affected by dredged material disposal and to develop design and maintenance guidance. As a result of experiments conducted to develop this guidance, some information also was obtained on functional differences between natural marshes and marshes recently established on dredged material.

PART II: GENERAL DESIGN CONSIDERATIONS

6. In order to establish a realistic simulation and to obtain meaningful test results, a number of considerations are necessary. In selecting the number of compartments within the natural system to be simulated, consideration must be given to the portions of the system directly affected by the proposed activity and to adjacent components that may be affected indirectly. Interface areas between system components may be of particular interest. If spatial gradients within the natural ecosystem need to be simulated, it will be necessary to establish two or more microcosm compartments to represent the gradient, since it is not practical to maintain a scaled gradient within a single laboratory unit.

7. Once representative compartments of the field prototype have been selected for simulation, the size of the various microcosm compartments must be determined. Of primary importance in this regard is that microcosm compartments must be areally proportional to their respective counterparts in the field prototype. Tidal exchanges of water between microcosm compartments also must be proportional to exchanges in the prototype. Actual prototype depths must be used in the microcosm because it is impractical to scale aquatic systems in the vertical without distorting ecosystem structure and function. If areas and tidal exchanges are properly proportioned, actual depths are used, and other environmental conditions such as light and temperature are properly simulated, functional relations within and between the marsh and estuarine components of the microcosm should be similar to those of the field prototype for a reasonable time period in the absence of major perturbations such as storms.

8. Microcosm studies must be limited primarily to the lower biological trophic levels due to restrictions on mobility and size. Fortunately, however, basic ecosystem functions such as mineral cycling and energy flow are usually dominated by the lower trophic levels. Modification of natural predation and grazing by larger animals may cause distortions in relative population abundances over time and must be considered in the design of microcosm experiments.

9. The exact size and configuration of microcosm units and the duration of testing will vary depending on the prototype situation to be simulated, the purpose of the investigation, and the availability of suitable space. Microcosms can be maintained outdoors, but for purposes of control and repeatability, an environmental chamber or greenhouse is recommended.

PART III: FIRST PILOT EXPERIMENT

Selection of a Field Prototype

10. The first pilot experiment was conducted using Barataria Bay, located near Grand Isle, Louisiana, as the prototype system for initial microcosm design and verification. The choice of Barataria Bay as the field prototype was based primarily on the following:

a. Availability of field data.

b. Shallow depth and small tidal amplitude.

c. Proximity to the U. S. Army Engineer Waterways Experiment Station (WES).

Microcosm Design

11. In the first pilot experiment the Barataria Bay system was broken into three component parts: marsh, estuary, and an interface zone - the tidal creek. Areas of these ecosystem components were proportioned and allocated to three Plexiglas tanks to form a three-compartment microcosm (Figure 2). Two of the tanks were 61 by 122 by 45 cm deep, while the third tank was 61 by 61 by 122 cm deep. Additional details on the physical characteristics of the microcosm are given in Table 1.

12. Data on Barataria Bay are conflicting as to the amount of exchange between the gulf and estuary. If the total volume of water is compared with the rate of freshwater and saltwater inputs during one tidal cycle, the amounts of exchange are negligible (Perret et al. 1971). If the tidal amplitude is compared with the average depth of the estuary, one sixth of the volume of the estuary is exchanged during each tidal cycle. In any case, descriptions of the movement of water through Barataria Bay (Perret et al. 1971, Hacker 1973) indicate that relatively little lateral mixing occurs. Apparently exchange between the gulf and estuary waters is relatively small when compared to the total volume of water involved, except during major storms. No quantitative information

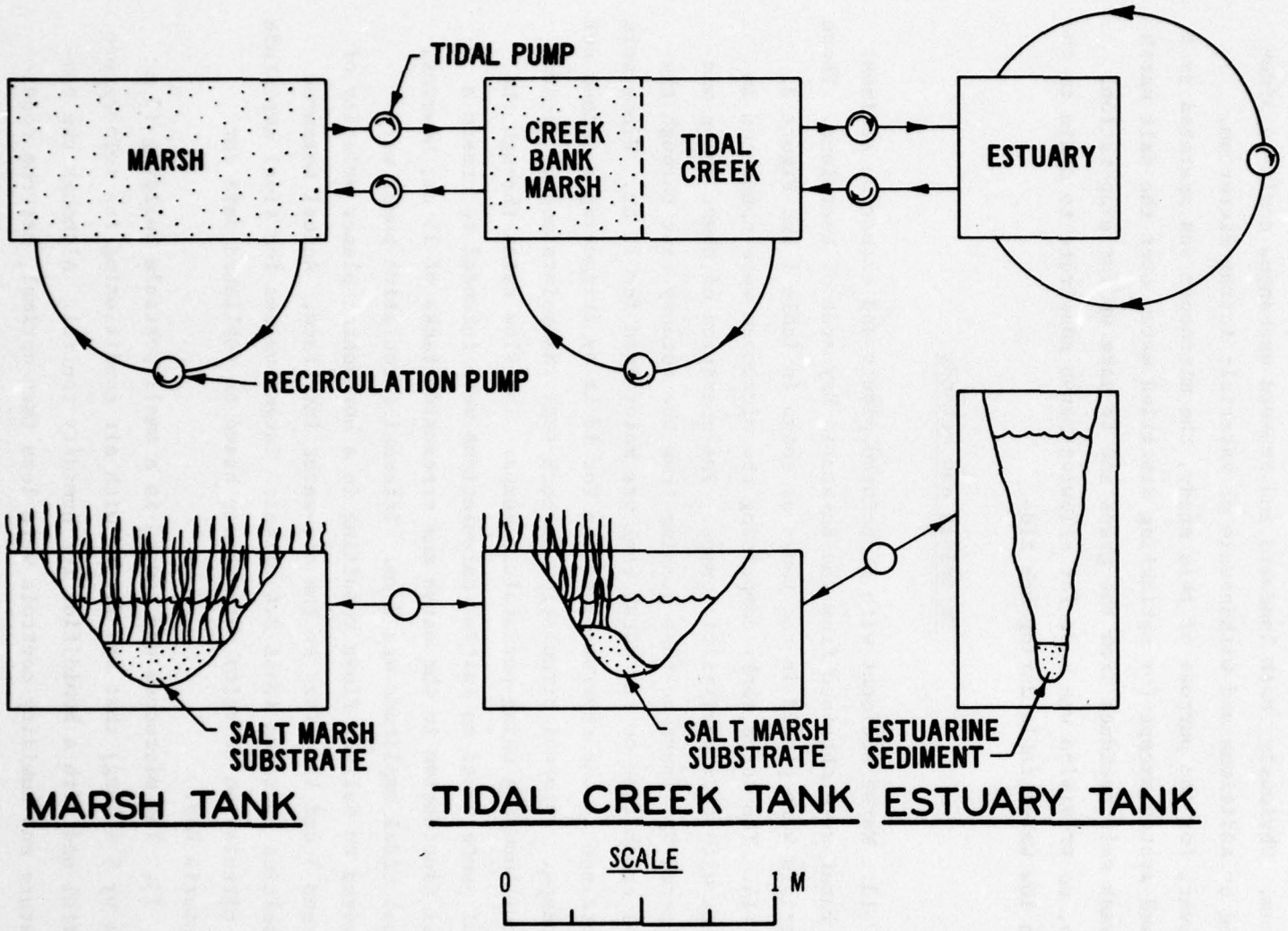


Figure 2. Compartmentalized marsh-estuarine microcosm

is available about landward inputs to the Barataria salt marsh ecosystem. Obviously, both landward and seaward exchanges could be simulated by additions and withdrawals of materials in the microcosm. However, for the purpose of this study, the microcosm was operated as a closed system except for sprinkling distilled water over the salt marsh to wash salt residues from the grass and to make up for evaporation. Also, no provision was made for allowing marsh substrate to drain to the mean low water table during ebb tide.

Materials and Methods

13. Marsh sediment with associated plants and estuarine sediment and water were obtained from the Barataria Bay area of Louisiana. These materials were placed in the tanks as shown in Table 1 and Figure 2.

14. The three tanks comprising the microcosm were connected in series with four peristaltic pumps. The operation of these pumps was triggered by timers so that pumping from the estuary tank through the tidal creek tank to the marsh tank was maintained for 12 hr. Flows were maintained in the reverse direction for 12 hr by triggering a second set of pumps. Internal circulation in each tank was maintained by closed-circuit pumping using peristaltic pumps. The flow rates through the tidal pumps based on initial calculations were intended to create a tidal fluctuation in the marsh and streamside tanks of 15 cm; however, actual tidal amplitude was 9 cm. Internal circulation pumps were targeted to deliver flows resulting in a horizontal planer velocity of between 3 and 15 cm/sec at the air-water interface. Actual measured velocities averaged about 2.4 cm/sec. Target values for tidal amplitude and circulation velocity were chosen based on published data for Barataria Bay.

15. The microcosm was housed in a small portable building (3 m wide by 6 m long) that was fitted with air conditioning for temperature control and with a humidifier for humidity control. Although the temperature and humidity controls were less than optimal, extreme conditions of high daytime temperatures and low humidities were avoided.

Humidity was maintained at about 60 percent relative humidity over a temperature range of 20° to 25°C.

16. Artificial lighting was provided by a bank of "Gro-Lux" lights consisting of 106 lamps (2.4 m in length). These lamps provided an illuminance of about 18,000 lux when measured at a distance of 46 cm from the light source. Illuminance readings taken during the experiment remained essentially constant. Since no differential radiation measurements were made, it is not known whether significant changes in spectral quality of light occurred during the experiment. Throughout the experiments, lights were operated by timers to give a 12-hr photoperiod. No attempt was made to simulate exact natural levels or cycles of temperature, humidity, or light because of facility limitations. In general, temperatures were higher and relative humidities and light intensities were lower in the simulation than natural conditions for the same months in southern Louisiana. The microcosm was established in October 1973 and operated for 7 months. Observations of the flora and fauna and measurements of water temperature, dissolved oxygen, pH, salinity, and water currents were made periodically throughout the experiment. A 48-hr intensive sampling of the simulation was conducted during March 1974, 6 months after establishment. Samples were taken at 2- to 4-hr intervals in each tank to measure diel and tidal cycles of carbon, nitrogen, phosphorus, and community metabolism. Chemical analyses were conducted according to methods recommended by the U. S. Environmental Protection Agency (US EPA 1971). Suspended bacteria were determined by plate count after culture on Zobell's medium No. 2216 at 21°C for 21 days. Eh profiles were measured with platinum electrodes. Speed and direction of water currents were measured with an electromagnetic current meter.

17. Community metabolism was estimated by the diurnal oxygen curve method of Odum and Hoskin (1958). Estimates of periphyton biomass were made by suspending glass slides immediately below the low tide surface levels of streamside and estuary tanks and 10 cm above the sediment in the estuary tank. However, accumulations of detritus and other solids on the slides resulted in overestimates of periphyton biomass.

18. Atmospheric reaeration coefficients were estimated by sparging tap water circulating in identical tanks with argon to remove dissolved oxygen and measuring the rate of dissolved oxygen recovery. Coefficients were obtained by linearly fitting a plot of the log of the dissolved oxygen deficit versus time for the duration of the aeration experiment. These reaeration coefficients were 0.100 and 0.283 mg O_2/ℓ/hr for the estuary and marsh tanks, respectively.

19. Results were evaluated on the basis of comparison with field data for the Barataria Bay ecosystem obtained from Ho (1971), Stowe et al. (1971), Perret et al. (1971), Hacker et al. (1971), and Brannon (1973).

Results

20. Representative fauna and flora of the Barataria Bay ecosystem existed in the microcosm throughout the pilot experiment. At least eight genera of algae and 30 genera of animals representing major phyla from Protozoa to Chordata were maintained in the simulation (Table 2). Animals included snails, crabs, shrimp, and small finfishes. The marsh flora was dominated by Spartina alterniflora with some Distichlis spicata.

21. Although seasonal senescence probably was beginning to occur in October when field materials were collected, marsh plants continued to grow in the microcosm through December. Most of the mature stems died during January and February and only a few new shoots had appeared by the termination of the experiment in April. Die-off may have been attributable to natural seasonal senescence or to a buildup of sediment salinities in the absence of sediment drainage as proposed by Barko et al. (1977).

22. During February and March, mats of benthic algae developed in the streamside tank along the edge of the marsh on the tidal creek sediment. Algal growths were typical of those found in similar Barataria Bay habitats. Filamentous algae also colonized the walls of the estuary tank. No attempt was made to control the growth of filamentous algae on the estuary tank walls, although this was an obvious distortion of the natural environment.

23. Sediment Eh profiles measured in the microcosm 6 months after establishment were within the range of those measured by Brannon (1973) in the Barataria Bay ecosystem (Table 3). This indicates that electrochemical conditions similar to those existing in the field prototype became reestablished in the microcosm despite some aeration and disturbance that occurred during collection and transport of field materials to the WES.

24. Several biological and chemical parameters were influenced by diel and tidal cycles (Figure 3). Concentrations of all aqueous chemical constituents were highest in the marsh and lowest in the estuary, indicating a net transport of nutrients from the marsh to the estuary through tidal fluxes. The ammonium nitrogen concentration gradient suggests that nitrogen was most likely the limiting nutrient since levels of ammonium declined from a high value in the marsh to below the level of detection in the tidal creek and estuary tanks. Nutrient concentrations in the estuary portion of the microcosm were lower than concentrations reported for the Barataria estuary (Table 3). Since the microcosm was operated as a closed system, it is likely that nutrients in the estuary tank were depleted by uptake by the large standing crop of benthic and filamentous algae.

25. Dissolved oxygen changes in the tidal creek and estuary tanks indicated that the tidal creek environment was more biologically active than the estuary (Figure 4). Typical diurnal variations in dissolved oxygen and community metabolism were observed. When dissolved oxygen amounts were corrected to reflect changes in volume due to tidal cycling and to account for atmospheric reaeration, primary productivity and community respiration calculations gave rates for the tidal creek of 5.4 and 8.2 g O_2/m^2/day and for the estuary of 3.5 to 3.1 g O_2/m^2/day, respectively (not including marsh grass metabolism). These values are within the range of values reported for coastal ecosystems by Odum et al. (1963), Copeland and Wohlschlag (1968), Pomeroy et al. (1972), and Cooper and Copeland (1973). The metabolic rates were slightly higher than data reported for the Barataria estuary (Table 3), possibly because the light-dark bottle method used by Stowe et al. (1971) did not measure

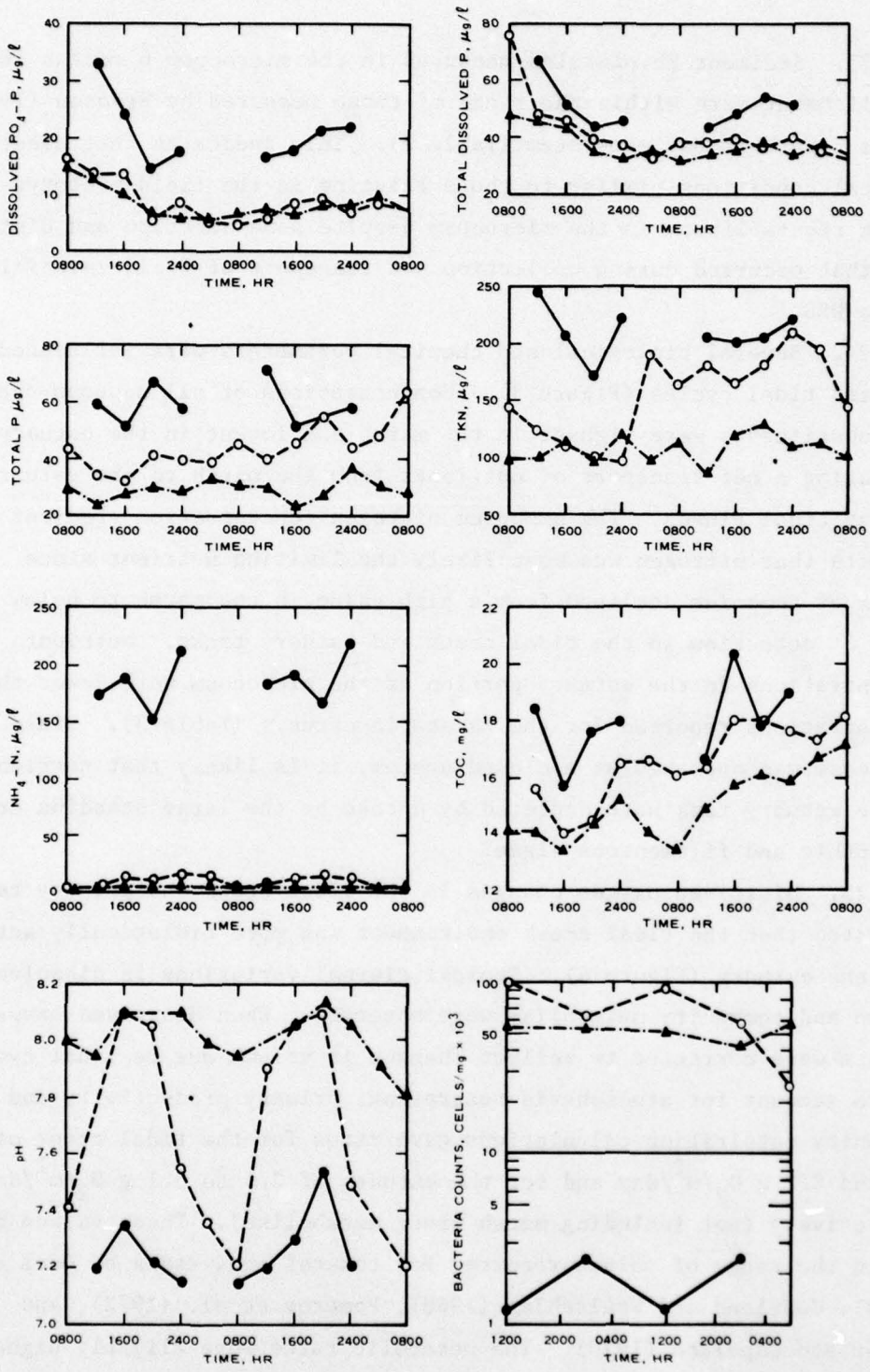


Figure 3. Diel changes in nutrient concentrations, pH, and suspended bacteria in marsh-estuarine microcosm 6 months after establishment. Closed circles denote marsh compartment, open circles denote tidal creek compartment, and closed triangles denote estuary compartment

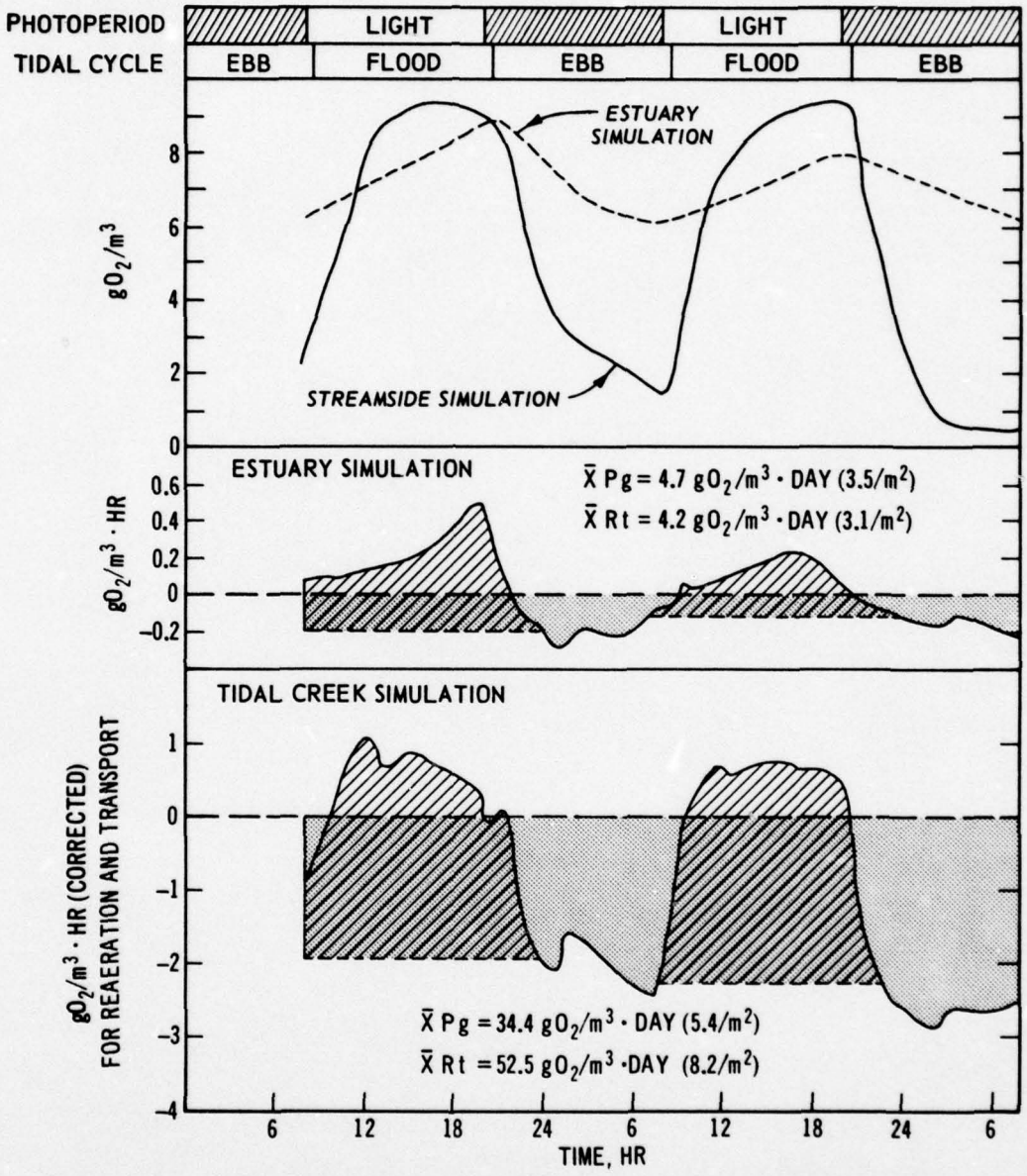


Figure 4. Diurnal variations in dissolved oxygen and metabolism of microcosm compartments 6 months after establishment. Metabolism is expressed as gross primary productivity (Pg) and total aquatic community respiration (Rt)

benthic metabolism, while the method used in this study estimated total metabolic rates.

PART IV: SECOND PILOT EXPERIMENT

Materials and Methods

26. Following the completion of the first pilot experiment, a second experiment was initiated on 10 July 1974. Barataria Bay, Louisiana, was again used as the field prototype and source of materials. The objective of the second experiment was to compare rates of community metabolism and nutrient flux in treatment and control marsh microcosms.

27. Each microcosm consisted of a marsh tank and an estuary tank, established and operated as described for the first experiment, except the growth of attached organisms on the walls of estuary tanks was controlled by daily scraping. Because of space limitations, the tidal creek tank was not used in the second experiment. In both treatment and control situations, estuary tanks were established using sediment and flood-tide water from Barataria Bay. The control marsh tank was established using marsh substrate with intact grass collected from the Barataria Bay area. The treatment marsh tank was used to simulate a marsh being established on dredged material. Fine-textured dredged material was obtained from an ongoing dredging operation near the location where other experimental materials were obtained. Transplants of Spartina alterniflora were obtained from the Barataria Bay salt marsh and established on the dredged material.

28. The second pilot experiment was conducted for a period of 6 months. Air and water temperatures, relative humidity and light intensities in the environmental chamber, pH, salinity, dissolved oxygen, and aboveground shoot height and numbers of live marsh plants were determined at daily to weekly intervals. Four months after establishment, an intensive 24-hr study with sampling at 0.5- to 4-hr intervals was conducted to evaluate diel and tidal fluxes of chemical and biological parameters. Parameters measured during the first pilot experiment also were measured during this experiment using similar methods.

Results

29. A noticeable bloom of benthic algae developed on the surface of the dredged material in the treatment marsh within 2 weeks of establishment and formed extensive mats within 2 months. Algal mats were completely absent from the surface of the control marsh. The surface of the control marsh had a much drier appearance than the treatment marsh at low tide and was interwoven with dead grass stems and other detrital material.

30. Algal colonies first appeared on the sediment surface of the treatment estuary about 6 weeks after establishment. Benthic algae in the treatment estuary developed mats that trapped oxygen and eventually floated to the surface, lost gas bubbles, and sank back to the sediment. Significant benthic algal blooms were never observed in the control estuary tank. Since both treatment and control estuaries were established with identical water and sediment, differences in benthic algal growth probably were caused by differences in material transported by tidal fluxes from the treatment and control marshes. The exact cause of these differences could not be explained by water-quality data obtained during the pilot experiment.

31. Van Raalte et al. (1974) observed that algal biomass increased on the marsh surface when light shading by marsh plants was decreased. However, shading by marsh plants in the control marsh tank did not appear to be sufficient to explain the almost complete absence of benthic algae on the surface of the marsh substrate. Water in the control estuary tank was visibly clearer, indicating that light limitation probably was not responsible for differences in algal growth. This conclusion was supported by observations using small beakers containing samples of the upper 10 cm of marsh substrate from the treatment and control marsh tanks. The beakers were placed under lights in the environmental chamber where no shading could occur. Algal mats developed on the substrate from the treatment marsh but did not develop on substrate from the control marsh. Differences in dissolved inorganic carbon, nitrogen, and phosphorus concentrations in the waters of the two

microcosms were not sufficient to explain differences in algal growth. Differences most likely can be attributed to differences in nutrient content of the two sediments. Golterman, Bakels, and Jakoks-Mögelin (1969) and Chiou and Boyd (1974) have shown that algae can derive phosphorus from sediments. It is not known if algae can derive other nutrients from sediments, although this is likely for nutrient-rich sediments. Ranwell (1964) and Barko et al. (1977) have shown that fine-textured sediments are generally rich in plant nutrients. Salt marsh sediments are generally low in plant nutrients, and marsh plants may be nutritionally dependent on newly accreted sediments (Ranwell 1964). Therefore, differences in algal growth on the sediments of the two marsh tanks may be attributable to differences in fertility of the sediments.

32. Transplants of Spartina alterniflora ranged in height from 10 to 30 cm. Over half of these plants died within the first 40 days of the experiment (Table 4). Larger transplants were more successful in becoming established, presumably due to greater root development and additional reserves of stored photosynthate. After this initial die-off, most plants survived for the duration of the experiment and produced numerous vegetative shoots. Plants increased in size as well as in number as mean height of the original transplants increased from about 16 cm to over 50 cm. At the termination of the experiment, shoot height of the treatment and control marshes was similar.

33. Data obtained from the treatment and control marsh microcosms are presented in Table 5. Average values for water temperature and salinity were similar in both treatment and control microcosms. Dissolved oxygen concentrations, pH, and sediment Eh were higher in the treatment than in the control. Concentrations of various forms of dissolved and particulate phosphorus and nitrogen generally were higher in the control than in the treatment. Differences between treatment and control marsh microcosms can be attributed to the greater abundance of detritus in the control marsh and the associated greater rates of microbial decomposition. These data also indicate that differences in functional characteristics of the two marsh tanks produced significant differences in the tidally linked estuary tanks, although the two

estuary tanks were identical at the beginning of the experiment. Nutrient concentrations in the marsh-estuarine microcosms generally were in the range of values reported for Barataria Bay (Ho, Schweinsberg, and Reeves 1970, Ho 1971) as well as other coastal ecosystems (Pomeroy 1960, Watt and Hayes 1963, Harrison 1973, Billen 1975).

34. Diurnal variations of pH and dissolved oxygen in the microcosms 4 months after establishment are shown in Figures 5 and 6. Dissolved oxygen concentrations were corrected for atmospheric reaeration and tidal transport, thus changes shown in Figure 6 represent biological uptake and production of oxygen. Dissolved oxygen data could only be obtained in the marsh tanks during times of flood tide.

35. Negative slopes of dissolved oxygen plots during the dark period provide estimates of the rate of aquatic community respiration (Figure 6). Aquatic community respiration in the treatment marsh tank was greater than in all other tanks. This probably was caused in part by the respiration of the extensive algal mats present on the surface of the treatment marsh.

36. Rates of community metabolism and the ratio of primary production to community respiration were higher in the treatment estuary than in the control estuary. Since both treatment and control estuary tanks were identical at the beginning of the experiment, differences in biological community metabolism of the estuary tanks must be attributed to differences in the treatment and control marsh tanks, which were linked by tidal fluxes to the estuary tanks.

37. Large dips in the dissolved oxygen rate-of-change curve for the treatment estuary tank during the light period indicate times when algal mats, made buoyant by oxygen bubbles produced through photosynthesis, would rise to the surface of the estuary tank and lose excess oxygen, resulting in a sudden decrease in the dissolved oxygen rate of change (Figure 7). Algal mats and associated gaseous oxygen losses were much more prevalent in the treatment estuary than in the control. These losses resulted in an underestimation of the actual rate of biological productivity. A more accurate estimate of productivity can be obtained by connecting the peaks in the daytime rate-of-change curve for the

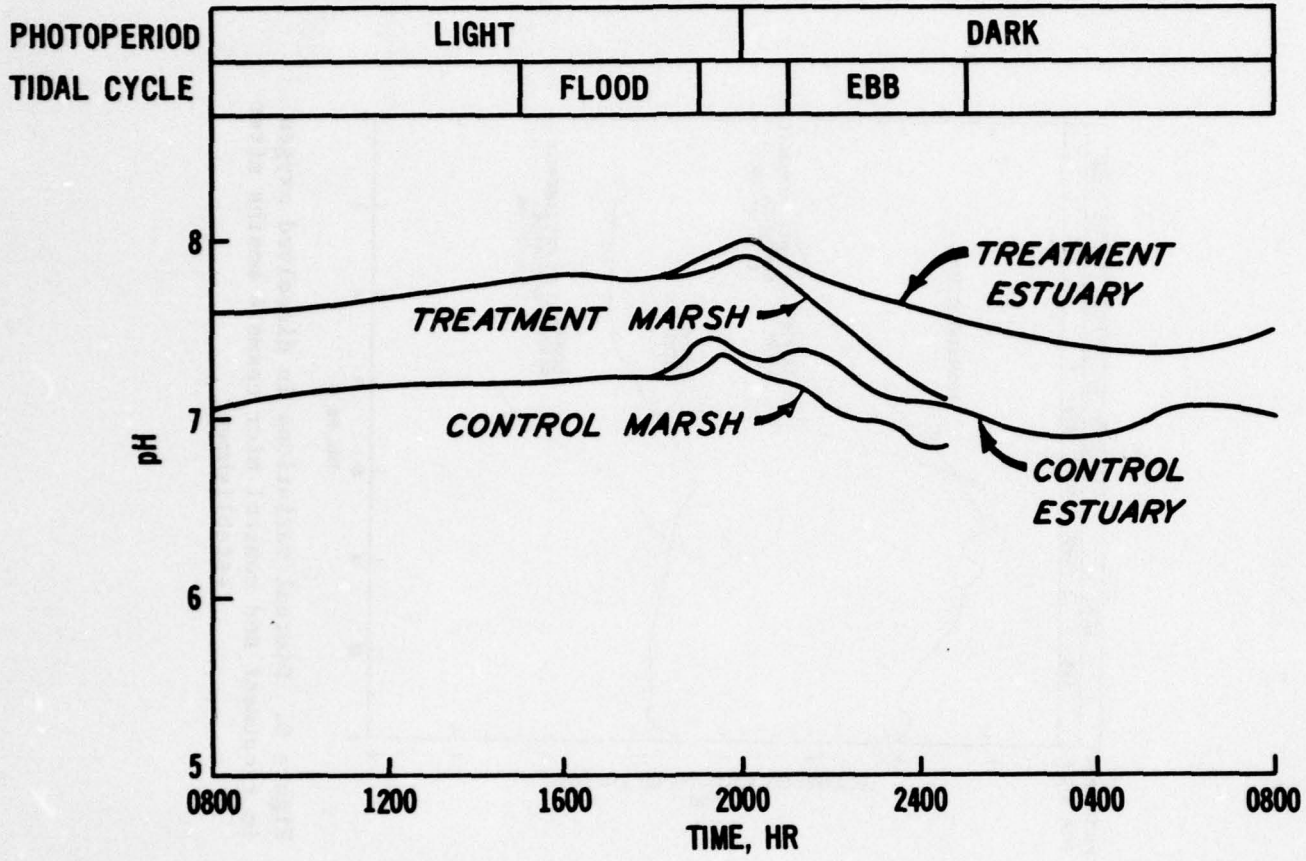


Figure 5. Diurnal variations in pH in treatment and control microcosms 4 months after establishment

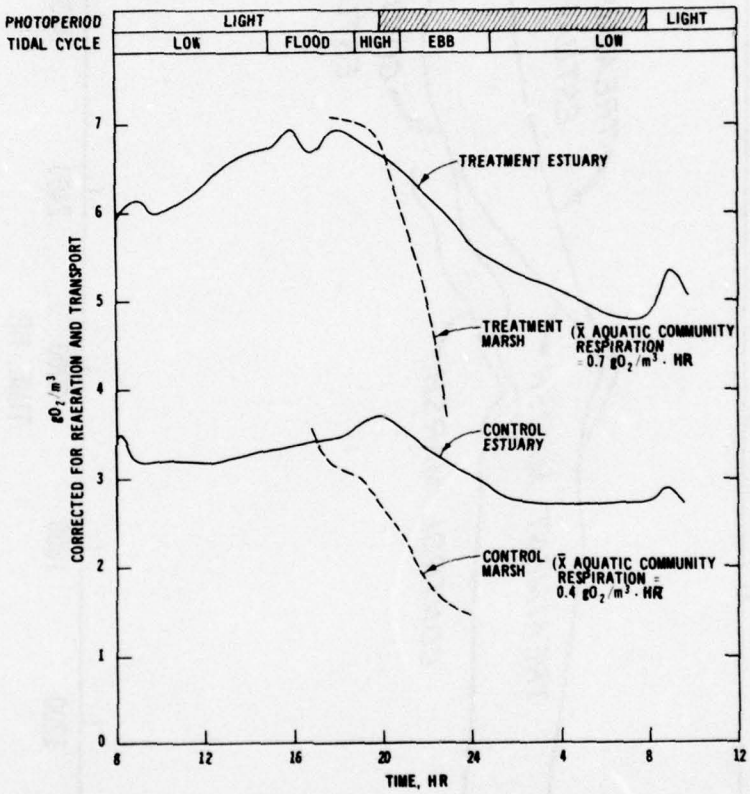


Figure 6. Diurnal variations in dissolved oxygen in treatment and control microcosms 4 months after establishment

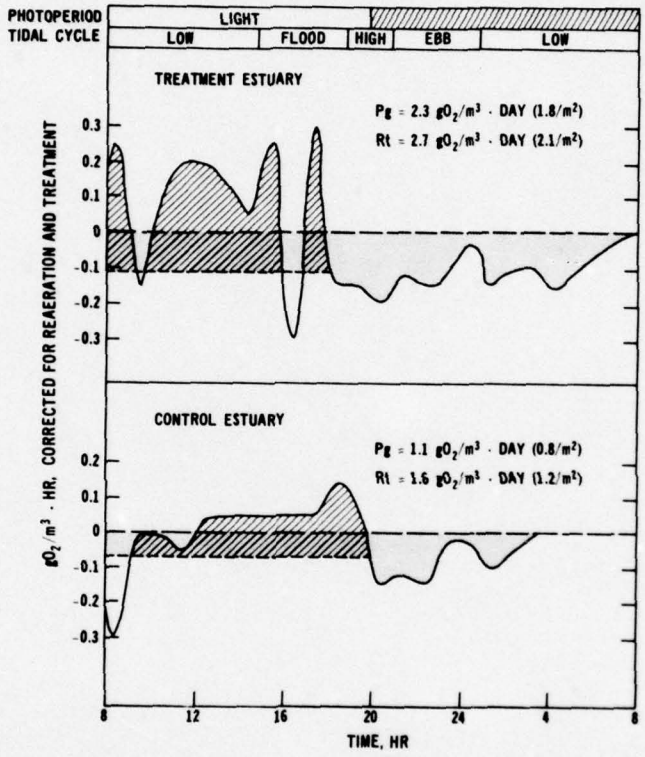


Figure 7. Variations in rates of change of dissolved oxygen concentrations and estuary community metabolism in treatment and control microcosms 4 months after establishment

treatment estuary and including the areas represented by the daytime dips in the productivity calculations. Results of this correction indicate that the treatment estuary actually produced more dissolved oxygen by photosynthesis during a 24-hr period than was used by the respiration of the total biological community.

PART V: TIDAL FLUX OF NUTRIENTS BETWEEN MARSH AND ESTUARINE COMPARTMENTS

38. Nutrient concentrations and tidal fluxes measured in the microcosm experiments were used to estimate fluxes of nitrogen, phosphorus, and carbon between marsh and estuarine compartments (Figure 8). The magnitudes of tidal transport of nitrogen and phosphorus from the estuary tanks were similar for the three data sets. Nitrogen transport was 4.2, 5.3, and 3.2 mg/day while phosphorus transport was 0.9, 1.9, and 1.8 mg/day for the first experiment and the control and treatment tanks of the second experiment, respectively. Tidal transport of nutrients from the natural marsh microcosms also was similar for both experiments. Nitrogen transport was 26.5 and 15.6 mg/day while phosphorus transport was 3.6 and 4.3 mg/day from the control marsh tanks for the first and second experiments, respectively. Phosphorus transport from the treatment marsh was similar to controls, but nitrogen transport from the treatment marsh was significantly less than for the controls.

39. Net nutrient fluxes also were calculated as the total amount of nutrient imported or exported per square metre of salt marsh so the rates could be compared on a unit surface area basis with field data. Although flux calculations were made for all measurable forms of each nutrient, only the rates based on total nutrient concentrations are presented in Figure 9.

40. In both experiments there was a net export of nitrogen, phosphorus, and carbon from the marsh to the estuary compartments. Nitrogen exports from the control marshes were predominantly in the form of ammonium and particulate nitrogen. In the first experiment, about half of the exported nitrogen remained in the tidal creek tank, with the other half being transported to the estuary tank. In the second experiment, the treatment marsh also exported particulate nitrogen, but the export of total nitrogen was reduced by a net transport of dissolved nitrogen. All of the marsh tanks also exported phosphorus in the particulate form. The phosphorus exported in the first experiment was contributed equally by the marsh and tidal creek tanks. In the first

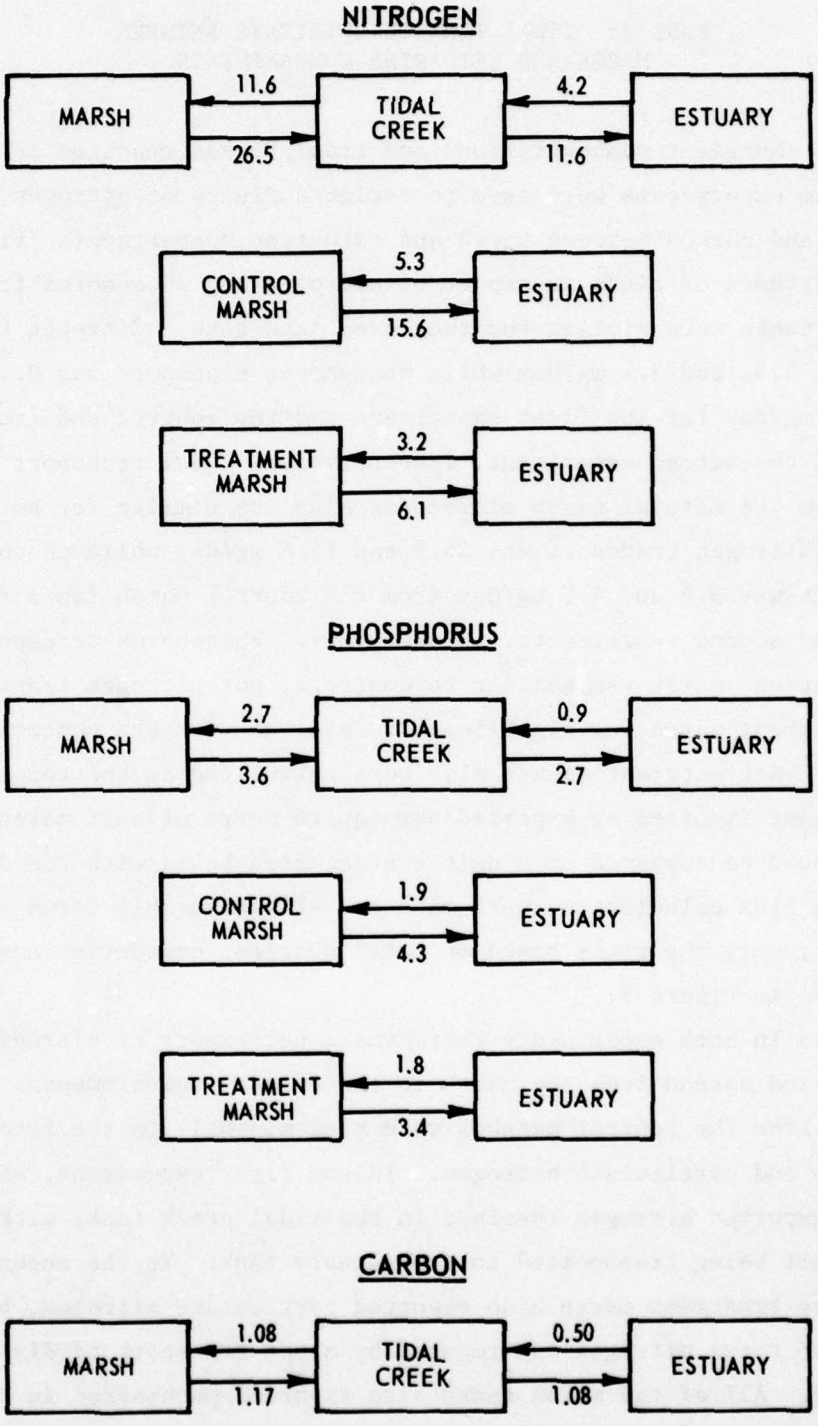


Figure 8. Tidal transport of nutrients between microcosm compartments. Units are in milligrams per day for nitrogen and phosphorus and grams per day for carbon

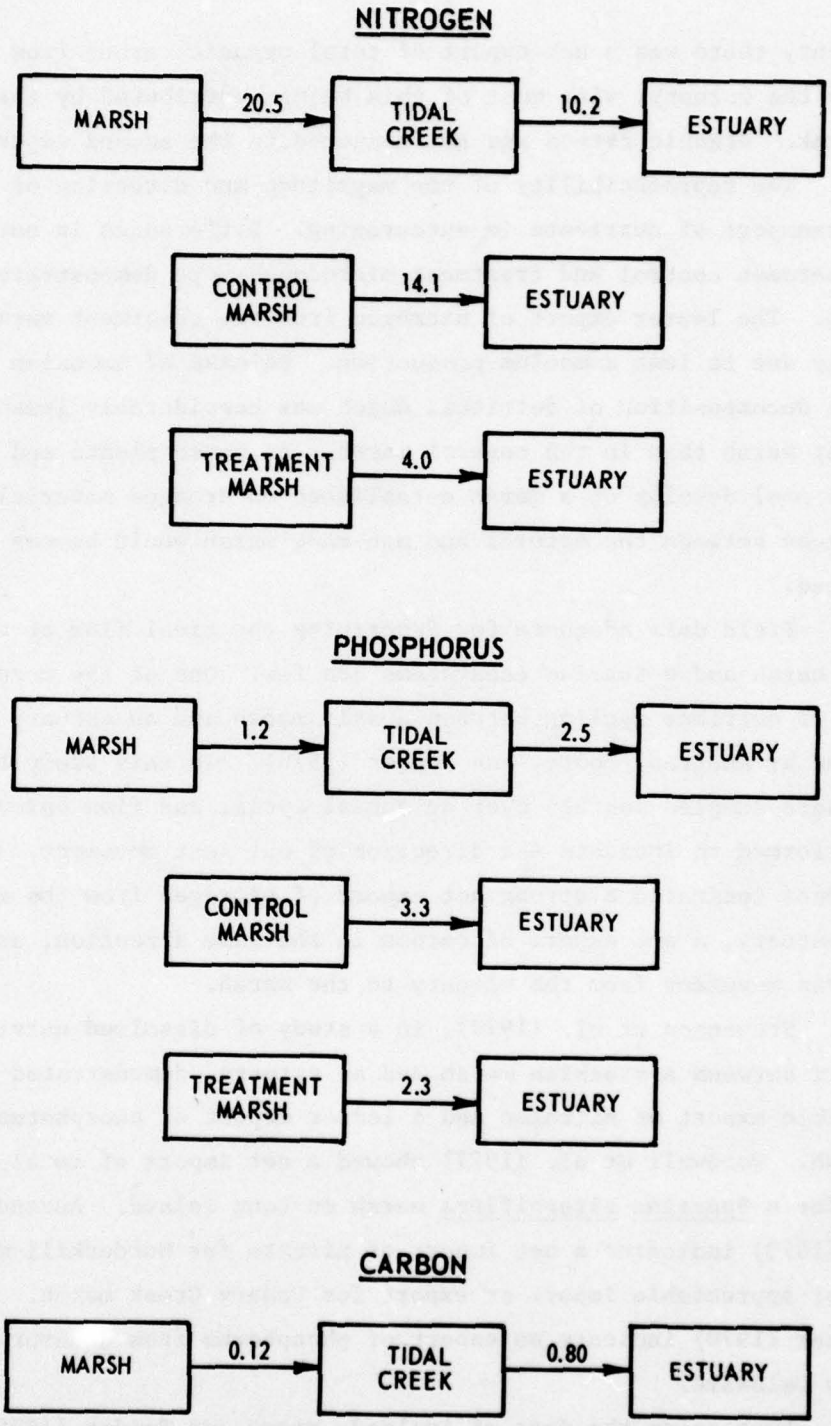


Figure 9. Net flux of nutrients between microcosm compartments. Units are in milligrams per square metre of marsh surface per day for nitrogen and phosphorus and grams per square metre per day for carbon

experiment, there was a net export of total organic carbon from the marsh to the estuary, with most of this being contributed by the tidal creek tank. Organic carbon was not measured in the second experiment.

41. The reproducibility of the magnitude and direction of the net tidal transport of nutrients is encouraging. Differences in nutrient export between control and treatment microcosms were demonstrated for nitrogen. The lesser export of nitrogen from the treatment marsh was primarily due to less ammonium production. Release of ammonium is coupled with the decomposition of detritus, which was considerably less in the treatment marsh than in the control marsh. As marsh plants and the detrital pool develop on a marsh established on dredged material, differences between the natural and man-made marsh would become less pronounced.

42. Field data adequate for describing the tidal flux of nutrients between marsh and estuarine ecosystems are few. One of the more complete studies of nutrient cycling between a salt marsh and an estuary was conducted by Axelrad, Moore, and Bender (1976). In this study two tidal creeks were sampled monthly over an annual cycle, and flux calculations were performed to indicate the direction of nutrient movement. These researchers indicated a strong net export of nitrogen from the marsh to the estuary, a net export of carbon in the same direction, and a net phosphorus movement from the estuary to the marsh.

43. Stevenson et al. (1977), in a study of dissolved nutrient transport between a brackish marsh and an estuary, demonstrated an appreciable export of nitrogen and a lesser export of phosphorus from the marsh. Woodwell et al. (1977) showed a net import of total organic carbon for a Spartina alterniflora marsh on Long Island. Aurand and Daiber (1973) indicated a net import of nitrate for Murderkill marsh and a lack of appreciable import or export for Canary Creek marsh. Reimold and Daiber (1970) indicate an export of phosphorus from a natural salt marsh in Delaware.

44. Expressing the data of Axelrad, Moore and Bender (1976), Stevenson et al. (1977), and Woodwell et al. (1977) on an areal basis, results in the net fluxes of nutrients shown in Table 6. Data on

nutrient fluxes obtained in the marsh-estuarine microcosm experiments, shown in Figure 9, compare favorably with respect to nitrogen. Net phosphorus fluxes in the microcosm experiments however were in the opposite direction from those of Axelrad, Moore, and Bender (1976). Phosphorus fluxes are extremely hard to determine with accuracy, however, due to the high affinity of sediments for adsorbing phosphorus. The flux of total organic carbon in the microcosm was similar to values reported by Axelrad, Moore, and Bender (1976) but differed from Woodwell et al. (1977).

45. Pickral and Odum (1977), in a study of the spatial and temporal distribution of benthic detritus in a Virginia salt marsh, indicated large exports of detritus during periodic storm events. They stress the importance of direct measurements of bedload, suspended load, and floating transport of detritus as well as indicate the overriding importance of storm events in controlling import-export processes. In the marsh-estuarine microcosm experiments bedload and floating transport were restricted due to the design and operation of the microcosm compartments.

46. Microcosms basically are not suited for studying the effects of storm events. The role of microcosm research is, therefore, a supplement to and not a substitute for field studies. Microcosms are useful for studying the day-to-day processes occurring in marsh-estuarine ecosystems, but these processes are not necessarily the primary ones controlling the overall functioning of these systems.

PART VI: DESIGN RECOMMENDATIONS

47. Based on the results of the two pilot experiments, desirable modifications and additions to the basic design concepts for marsh-estuarine microcosms were formulated. These modifications include:

a. Increasing the depth of marsh substrate to exceed the depth of active plant root penetration (45 to 55 cm).

b. Installing a drainage system in the marsh tanks to simulate tidal groundwater movement.

c. Using multiple marsh tanks in series to simulate spatial or elevational gradients in the salt marsh.

d. Using a water distribution/circulation system to achieve uniform, realistic water velocities.

e. Removing attached periphyton from tank sides and circulation systems frequently.

f. Simulating exchange rates between adjacent freshwater and marine systems and the marsh and estuary through proportionate, periodic withdrawals and additions to the microcosm.

48. A schematic of one possible configuration of a marsh-estuarine microcosm embodying the required design concepts is shown in Figure 10. The relative size and number of tanks used in a simulation would vary according to the size and complexity of the prototype and the purpose of the experiment. Areas of microcosm compartments should be proportional to areas of their counterparts in the prototype, and depths in the microcosm must be equivalent to those in the prototype. Horizontal gradients should be simulated through the use of discrete microcosm units connected in series.

49. In choosing an appropriate size for a microcosm, several experimental trade-offs should be considered. Smaller microcosms allow greater replication and are more economical to construct, while larger microcosms are less affected by destructive sampling and offer fewer distortions due to boundary conditions.

50. There also are significant technical trade-offs among housing microcosms in environmental chambers, in greenhouses, or in the field, with environmental control being sacrificed for more natural environmental conditions. When accurate control of water temperature is

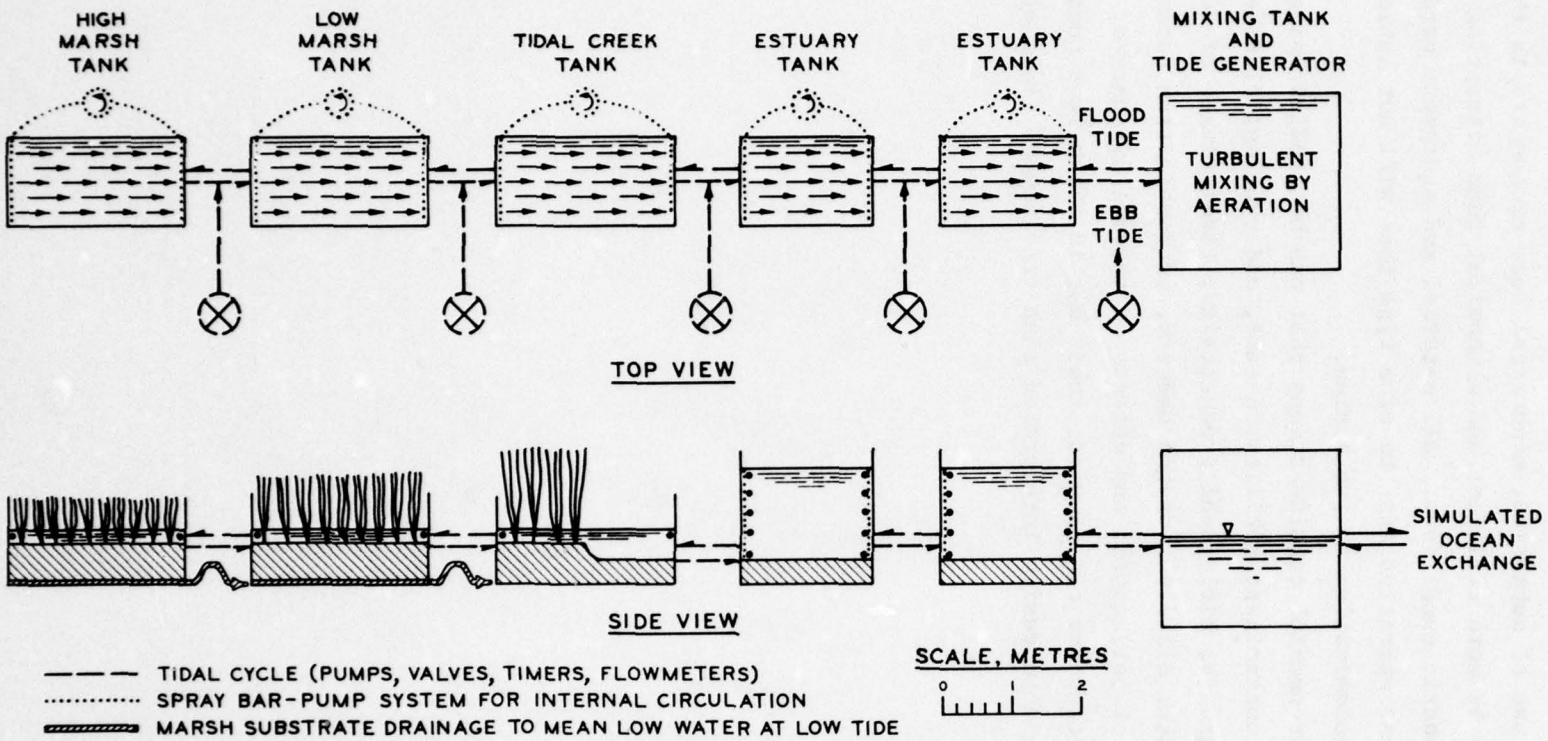


Figure 10. Diagrammatic representation of a compartmentalized marsh-estuarine microcosm

required, the use of submersed, mechanical heat exchangers in the microcosm generally is more efficient and economical than attempting to control atmospheric conditions. All material and equipment used for construction and operation must be of a type that will not introduce significant contamination to the system.

51. Environmental considerations that can be studied using microcosms include contaminant mobility, uptake, and cycling; plant establishment and growth; biological productivity; tidal fluxes of nutrients and contaminants; dissolved oxygen budgets; eutrophication potential; toxic effects of pollutants; and effects of thermal discharges. In cases where microcosms can be used, their use is often less costly and results may be more easily interpreted than traditional field study approaches.

PART VII: SUMMARY AND CONCLUSIONS

52. Technical limitations of traditional field study approaches for evaluating effects of perturbations to salt marsh-estuarine ecosystems suggest a role for microcosm studies in which transport processes, environmental conditions, and perturbations can be controlled, reproduced, and accurately measured. This study was conducted to design and investigate the feasibility of using such microcosms for evaluating effects of dredged material disposal on the ecology of marsh-estuarine systems. Two pilot experiments were conducted to form a basis for guidance on microcosm design and maintenance and for recommendations on potential applications to environmental problems.

53. Based on results of this investigation, the following conclusions can be drawn:

a. Natural marsh-estuarine biological communities can be maintained in appropriately designed microcosms.

b. Chemical gradients among different marsh and estuary compartments of the microcosm were detectable and sufficient for making flux calculations of mineral cycling.

c. Concentrations and dynamics of electrochemical and biological parameters in the marsh-estuarine microcosms were within the range of values reported for Barataria Bay and other coastal ecosystems.

d. The two experiments demonstrated the reproducibility of data obtained from marsh-estuarine microcosms.

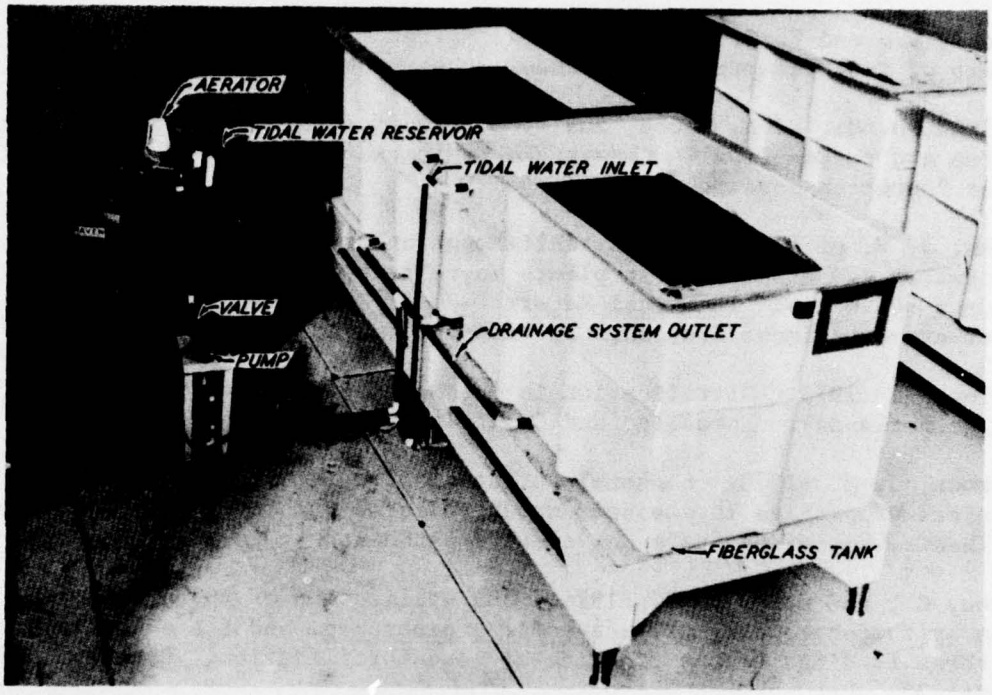
e. Differences between the treatment and control marsh microcosms were demonstrated and attributed predominantly to the larger detritus pool and associated microbial activity in the control marsh.

54. Based on the results of the two pilot experiments, final design recommendations were formulated. If these design criteria are met, approximate similitude between microcosm and prototype with respect to biological and chemical rates can be achieved. Microcosm experiments generally should not be more than 1 year (one growing season) in duration because of potentially significant distortions developing in biological community structure and function and because of the absence of major natural perturbations such as storm events.

55. Microcosms offer significant potential for understanding the effects of engineering activities and resource management alternatives on ecological functions of marsh-estuarine systems. A wide range of environmental considerations may be studied. Microcosms also are useful in supplementing other research approaches in the development and evaluation of mathematical models. In cases where microcosm studies are appropriate, their use is generally less costly and the results more interpretable than field study approaches. The microcosm approach may be especially useful when treatment-control comparisons, significant replication, or special study techniques are required. Marsh-estuarine microcosms can be used effectively as ecosystem-level bioassays to evaluate effects of man's activities on important biological and chemical processes that are difficult to study in the field.

56. Microcosms are not appropriate for evaluating things such as impacts on species diversity or effects on migrations of important estuarine fishes. Also, microcosms obviously cannot be used effectively to study overall effects of many large-scale coastal perturbations such as hurricanes or flood-level freshwater inflows. However, for the latter two examples, some aspects of the problems could be isolated and simulated in microcosms to understand the nature of effects on basic ecosystem functions. For these and other applications, if approximate similitude of biological and chemical rates between microcosm and prototype is achieved on a surface area basis, results can be extrapolated in a meaningful manner to field conditions. Extrapolation requires the use of a surface area scale factor, or microcosm results can be incorporated with an appropriate numerical model to simulate system dynamics on a larger time and space scale.

57. Results of initial experiments conducted as part of this study indicate that numerous applications of marsh-estuarine microcosms are feasible. Several versions of these microcosms have been used to investigate problems associated with dredged material disposal. Examples include studies of marsh plant establishment by Barko et al. (1977) (Figure 11) and ongoing investigations of heavy metal uptake by marsh plants.



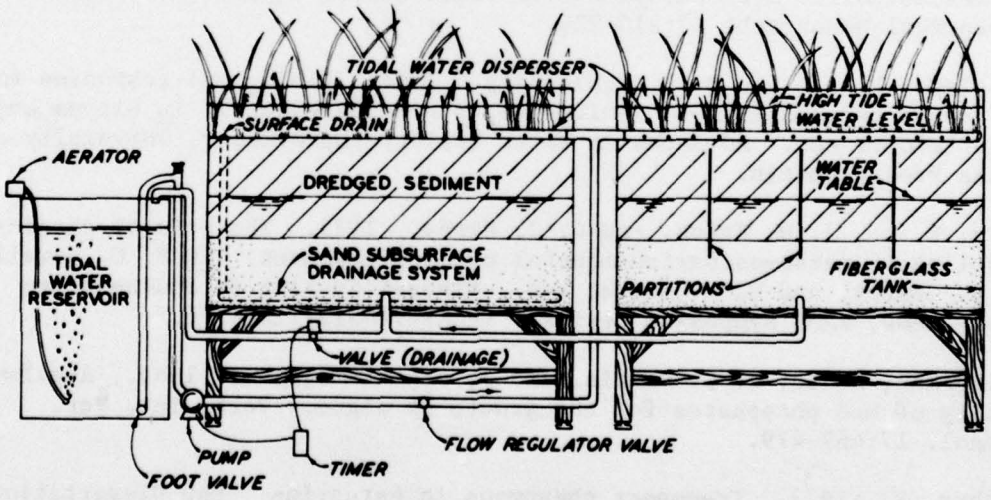


Figure 11. Schematic and photograph of a marsh microcosm for investigating factors affecting establishment and growth of marsh plants on dredged material

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Table 1

Physical Characteristics of the Marsh-Estuarine Microcosm

Parameter	Marsh Tank	Tidal Creek Tank	Estuary Tank
Marsh Surface Area, m^2	0.73	0.25	--
Estuary Surface Area, m^2	--	0.48	0.37
Water Depth at Low Tide, cm	0	17*	62
Water Depth at High Tide, cm	9	24*	93
Water Volume at Low Tide, ℓ	2	80	230
Water Volume at High Tide, ℓ	80	115	343
Marsh Sediment Depth, cm	30	30	--
Estuary Sediment Depth, cm	--	11	15

* These numbers apply to that portion of the tank which was always submerged.

Table 2

Biota Identified in the Marsh-Estuarine Microcosm at the Termination of the First Pilot Experiment

Taxa	Common Name
CHLOROPHYTA	
Cladophora sp.	Filamentous green algae
Enteromorpha sp.	Green algae
CHRYSOPHYTA	
Coscinodiscus sp.	Diatom
Nitzchia sp.	Diatom
Naviculum sp.	Diatom
Chaetoceras sp.	Diatom
PYRROPHYTA	
Ceratium sp.	Dinoflagellate
Peridinium sp.	Dinoflagellate
TRACHEOPHYTA	
Spartina alterniflora	Salt marsh cordgrass
Distichlis spicata	Salt grass
PROTOZOA	
Peridinium sp.	Dinoflagellate
Ceratium sp.	Dinoflagellate
Diffugia sp.	Sarcodinian protozoan
Zoothamnium sp.	Ciliate
Unidentified spp.	
COELENTERATA	
Hydrozoa	
Bimeria franciscana	Hydrozoan
Unidentified spp.	Hydrozoan
CTENOPHORA	
Beroe ovata	Ctenophore
PLATHYHELMINTHES	
Turbellaria	
Unidentified spp.	Flatworm

(Continued)

Table 2 (Concluded)

Taxa	Common Name
NEMADODA	
Unidentified spp.	Nematode
BRYOZOA	
Membranipora sp.	Bryozoan
ANNELIDA	
Polychaeta	
Neanthes succinea	Polychaete
MOLLUSCA	
Gastropoda	
Littorina irrorata	Salt marsh periwinkle
Neritina reclivata	Snail
Melampus bidentatus	Snail
Pelecypoda	
Modiolus demissus	Salt marsh clam
Rangia cuneata	Brackish water clam
ANTHROPODA	
Crustacea	
Balanus sp.	Barnacle
Gammarus sp.	Amphipod
Penaeus setiferus	White shrimp
Penaeus aztecus	Brown shrimp
Callinectes sapidus	Blue crab
Rhithropanopeus harrisii	Mud crab
Sesarma recticulatum	Box crab
Uca pugnax	Fiddler crab
CHORDATA	
Osteichthyes	
Prionotus alatus	Sea robin
Prionotus salmonicolor	Sea robin
Paralichthys lethostigma	Southern flounder
Symphurus plagiusa	Blackcheek tonguefish

Table 3

Comparison of Microcosm Data With Data From Barataria Bay

Parameters	Estuary Tank*	Tidal Creek Tank*	Marsh Tank*	Barataria Bay Estuary	Barataria Bay Tidal Creek	Barataria Bay Marsh
Sediment Eh, mV						
Profile: 0 cm	+35	-30	+155			
1 cm	-35	-45	+100		-150 to +90**	-400 to +80**
5 cm	-105	-140	-140		-250 to +50**	-225 to +50**
10 cm	-140	-145	-175		-280 to -40**	-350 to -100**
TKN, µg/ℓ	106	157	210			
NH_4-N, µg/ℓ	<10	11	184	30†		
NO_3-N, µg/ℓ	<10	<10	<10	<10†		
PO_4-P, µg/ℓ	9	9	21	10†		
Total P, µg/ℓ	28	42	56	110†		
Total organic C, mg/ℓ	15.0	16.6	17.9			
Dissolved organic C, mg/ℓ	14.9	15.9	18.6			
Suspended bacteria, cells/ml x 10^3	50	70	1.7			

(Continued)

* Averages based on sampling at 2- to 4-hr intervals for 48 hr, 10-11 April 1974.

** Ranges for 1972 (Brannon 1973).

† Data for April 1969 (nitrogen) and April 1970 (phosphorus) (Ho 1971).

Table 3 (Concluded)

Parameters	Estuary Tank	Tidal Creek Tank	Marsh Tank	Barataria Bay		
				Estuary	Tidal Creek	Marsh
Gross primary productivity, g O_2/m^2/day	3.5††	5.4††			2.2‡	1.4‡
Total community respiration, g O_2/m^2/day	3.1††	8.2††				
Accumulation of periphyton and solids on suspended glass slides, g dry wt/ m^2/day	9.0‡‡	38.0‡‡				

†† Metabolic values for submerged community only.
‡ Calculated from light-dark bottle data for epiphytic and phytoplankton communities, June-October 1970 (Stowe et al. 1971).
‡‡ Based on 15 days of accumulation.

Table 4

Changes in Numbers of Live Shoots of *Spartina alterniflora* Transplanted on Dredged Material in the Treatment Marsh Microcosm

Category	Time, days				
	0	20	40	60	80
Original transplants	175	131	81	78	78
New shoots	0	0	2	42	76
Total shoots	175	131	83	120	154

Table 5

Comparison of Treatment and Control Microcosms

Parameters	Control Tanks		Treatment Tanks	
	Marsh	Estuary	Marsh	Estuary
Temperature, ^{o}C	24.1	23.8	24.6	24.2
pH	7.1	7.1	7.6	7.6
Salinity, g/ℓ	17.6	17.7	17.1	17.2
Dissolved oxygen, mg/ℓ	2.5	3.1	6.2	6.4
Sediment Eh, mV, at				
depths of: 0 cm	+52	--	+102	--
1 cm	+ 2	--	+27	--
2 cm	-38	--	-26	--
4 cm	-98	--	-58	--
Total P, µg/ℓ	43	38	34	34
Particulate P (total), µg/ℓ	9	4	10	4
Dissolved P (total), µg/ℓ	34	34	24	30
PO_4-P, µg/ℓ	30	26	24	21
Dissolved "organic" P, µg/ℓ	4	8	0	9
Total N, µg/ℓ	156	103	61	62
Particulate N (total), µg/ℓ	87	23	7	1
Dissolved N (total), µg/ℓ	69	80	54	61
NH_4-N, µg/ℓ	52	43	44	30
NO_2+NO_3-N, µg/ℓ	14	16	8	9
Dissolved "organic" N, µg/ℓ	3	21	2	22

Table 6

Literature Values for Net Fluxes of Nutrients From Salt Marshes*

Nutrient	Salt Marsh			
	Ware Creek**	Carter Creek**	Gott's Marsh†	Flax Pond††
Nitrogen, mg m^{-2} day^{-1}	7.7	10.9	11.3	
Phosphorus, mg m^{-2} day^{-1}	-2.15	-0.18	0.5	
Organic carbon, g m^{-2} day^{-1}	0.32	0.39		-0.15

* Positive numbers indicate marsh export. Negative numbers indicate marsh import.

** Data adapted from Axelrad, Moore, and Bender (1976).

† Data adapted from Stevenson et al. (1977). Data are for dissolved forms only.

†† Data adapted from Woodwell et al. (1977).

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

United States. Waterways Experiment Station, Vicksburg, Miss.
Design of a laboratory microcosm for evaluating effects of dredged material disposal on marsh-estuarine ecosystems / by Ecosystem Research and Simulation Division, Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
40, [8] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-52)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 1D08.
References: p. 38-40.

1. Dredged material. 2. Dredged material disposal. 3. Ecosystems. 4. Environmental effects. 5. Estuaries. 6. Microcosms. 7. Salt marshes. 8. Tidal marshes. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-52.
TA7.W34 no.D-78-52